UPPER RIO GRANDE WATER OPERATIONS MODEL
Physical Accounting Model Documentation

Table of Contents

List of Tables

List of Figures

UPPER RIO GRANDE WATER OPERATIONS MODEL

PHYSICAL ACCOUNTING MODEL DOCUMENTATION

Introduction

The accounting of reservoir losses and storage described in this document is used at six reservoirs and include 1) identification and allocation of losses associated with the construction and operation of the reservoir, and 2) isolating losses associated with importation and management of San Juan-Chama Project water. The process of identifying and allocating losses are handled simultaneously under three loss conditions (present, pre-reservoir and hypothetical). The loss determinations are similar, yet distinct for each reservoir. The approved loss rates for transportation of San Juan-Chama Project water are also described.

The physical accounting model primarily solves for inflow and then calculates all the additional loss and storage data to report and store in the database. This is the same operation that the Bureau of Reclamation daily water operations programs currently performs, but the physical accounting model will improve the accounting process by linking the releases of San Juan-Chama water to the inflows of the next down stream reservoir. The physical accounting model calculates total water storage, Rio Grande storage, San Juan-Chama Project water storage, and in some reservoirs, sediment inflow and storage.

River Accounting

In the reaches between Heron Dam and Elephant Butte Reservoir there are loss rates and travel time lags for San Juan-Chama water as shown in **Table 1**. The Rio Grande Compact Commission has approved these loss rates. The difference between the physical loss, calculated by the total water simulation, and the loss from the San Juan-Chama will be accounted for as Rio Grande loss.

Table 1. San Juan-Chama Project Water Loss Rates and Travel Time Lags.

Reach	Loss (%)	Lag
Heron to El Vado	0.00	0 day
El Vado to Abiquiu	1.10	1 day
Abiquiu to Otowi	0.90	1 day
Otowi to Cochiti	0.33	0 day
Otowi to Jemez	0.35	0 day
Cochiti to Elephant Butte:		
Jan	2.40	3 days
Feb	2.80	3 days
Mar	3.80	3 days
April	4.70	3 days
May	5.20	3 days
Oct	3.30	3 days
Nov	2.80	3 days
Dec	2.40	3 days

Heron Reservoir

Heron Reservoir is operated in compliance with the Rio Grande Compact. Two basic principles control the water release schedule from Heron Reservoir. The first is the authorized development of San Juan-Chama Project supplemental irrigation and municipal and industrial water demands that result in increased depletion of the Rio Grande. These depletions are offset by releases of San Juan-Chama water from Heron Reservoir sufficient to assure that no residual effect occurs to natural waters of the Rio Grande due to project operations. In addition, downstream contractors such as the City of Albuquerque and the Middle Rio Grande Conservancy District (MRGCD) convey other project waters past Otowi for use.

Secondly, carry-over storage is not permitted in Heron Reservoir from one year to the next. Contracted water not called to be released by December 31, would remain in Heron Reservoir as part of the project supply and would no longer belong to the individual contractor. In the past, Reclamation negotiated temporary waivers with contractors that allows carry-over until April 30 in order to provide release rates on the Rio Chama that would enhance the fishery between El Vado and Abiquiu Reservoirs during the winter and provide flexibility in managing river flows. The no carry-over stipulation results in the various contractors seeking storage in reservoirs downstream of Heron for their unused water. El Vado, Abiquiu, Jemez Canyon, and Elephant Butte reservoirs have been used for storage of San Juan-Chama waters. Another factor that influences Heron releases is ice cover on the reservoir and the resulting safety issues. If Heron is drawn down quickly when iced over or nearly completely iced over, hazardous conditions develop. Releases would be terminated until conditions are safe. During late March or April, any San Juan-Chama Project water not released because of unsafe winter operation conditions, will be released at a time when it is assured to meet the same purposes as if it had been released during the winter months, provided the necessary waivers have been granted.

The NRCS/NWS coordinated runoff forecast is used to estimate the period of time during the spring runoff that the Rio Chama is expected to exceed channel capacity below Abiquiu Reservoir, thus preventing a release of San Juan-Chama Project water from Abiquiu Reservoir. Between the time of ice melt on the reservoir and the time when spring runoff reaches full channel capacity, San Juan-Chama replacement water requirements downstream are estimated and are released from Heron Reservoir.

Inflow Calculations

Inflow to Heron Reservoir consists of imported San Juan-Chama Project water diverted at Rio Blanco, Little Oso, and Oso, delivered through Azotea Tunnel (measured at the tunnel outlet), and Rio Grande water from Willow Creek, which are conjointly measured at the Willow Creek above Heron Reservoir gage. The Rio Grande inflow also includes flow from the intervening area below the gage and the area around the reservoir such as Horse Lake Creek.

Accounting Model Inflow

In the physical accounting model, preliminary calculations for determining the Rio Grande inflow to Heron Reservoir are performed daily, but the final determination of Rio Grande inflow is made at the end of each month for the following three reasons.

1. The ratio inflow method (see below) was initially derived as a monthly method, making the amount of Rio Grande pool uncertain until after the last day of the month.
2. The San Juan-Chama Project portion of the Rio Grande Compact accounting is done on a monthly basis.
3. During much of the year, releases from Heron Reservoir are usually made near the end of each month. To operate the reservoir at a lower cost and to reduce the number of visits to Heron Dam, fewer but larger releases are made.

Several different calculations (methods) are used to compute the Rio Grande inflow for the physical accounting model. The method or combination of methods that provides the most meaningful estimate of Rio Grande inflow is then selected based on the daily-accumulated values at the end of the month. Attempts at determining which method(s) govern are also performed throughout the month using the cumulative daily values up to the date of the computations. The methods include ratio inflow, seepage from the dam, and net end of month gain (the term used in the water accounting reports). The final determination of Rio Grande inflow is made at the end of the month.

Mass Balance Equation

The general mass balance equation for reservoirs is of the following form:

$$S_t - S_{t-1} - I - P_t + E_t + O = 0$$

where:

S_t	is total storage today, in acre-feet
S_{t-1}	is total storage yesterday, in acre-feet
I	is total inflow to reservoir, in acre-feet per day
E_t	is total evaporation, in acre-feet per day
P_t	is total precipitation, in acre-feet per day
O	is total outflow from the reservoir, in acre-feet per day

Since there are two sources of water into Heron Reservoir, the inflow and outflow parameters of the equation can each be separated into two components as follows:

$$\begin{aligned} I &= I_{rg} + I_{sj} \\ O &= O_{rg} + O_{sj} \end{aligned}$$

where:

I_{rg}	is Rio Grande inflow to reservoir, in acre-feet per day
I_{sj}	is San Juan-Chama inflow to reservoir, in acre-feet per day
O_{rg}	is Rio Grande outflow from the reservoir, in acre-feet per day
O_{sj}	is San Juan-Chama outflow from the reservoir, in acre-feet per day

The only storage allowed in Heron Reservoir is San Juan-Chama water, so the storage parameter is assumed to be only the total storage of the reservoir. Therefore, the mass balance equation becomes:

$$S_t - S_{t-1} - I_{rg} - I_{sj} - P_t + E_t + O_{rg} + O_{sj} = 0$$

Solving for the Rio Grande inflow component results in the following equation:

$$I_{rg} = S_t - S_{t-1} + O_{rg} + O_{sj} + E_t - P_t - I_{sj}$$

Because of the large storage volume of Heron Reservoir (400,000 acre-feet) compared to the small natural inflow volume (average of 2,000 acre-feet per month), the mass balance equation often results in negative Rio Grande inflows. Therefore, other methods for determining the Rio

Grande inflow were developed. The methods include ratio inflow, seepage from the dam, and net end of month gain.

Ratio Inflow Method

The ratio method attempts to use stream gage information to compute the Rio Grande inflow. The San Juan-Chama inflow is known, since the flow from Azotea tunnel is measured at the outlet and an established reach loss (Azotea outlet flow times 0.002) is applied for the reach from the tunnel to the Willow Creek above Heron gage (above Heron gage). Subtracting the San Juan-Chama component from the abv. Heron gage results in the natural flow volume at the above Heron gage. The resulting natural flow volume at the gage is adjusted by a correlation or ratio factor (thus the term ratio method) to account for the intervening flow between the above Heron gage and Heron Dam. The ratio factors were developed based on a study of monthly flows at the above Heron and Willow Creek at Parkview gages for the period from 1943 to 1970. The ratio factors determined were 1.20 for “tributary flows above” greater than 360 acre-feet per month and 2.46 for “tributary flows above” less than or equal to 360 acre-feet per month. The daily calculations for the ratio method are summarized in the following equations:

$$Q_{sj\,calc} = Q_{az} \bullet 0.998$$

$$I_{rg\,tributary} = Q_w - Q_{sj_{calc}}$$

where:

$Q_{sj_{calc}}$ is calculated San Juan-Chama flow at the Willow Creek gage, in acre-feet per day

Q_{az} is gaged flow from Azotea Tunnel, in acre-feet per day

$I_{rg_{tributary}}$ is tributary Rio Grande inflow at the Willow Creek gage, in acre-feet per day

Q_w is gaged flow at Willow Creek above Heron, in acre-feet per day.

$$I_{rg\,ratio\,low} = I_{rg\,tributary} \bullet (2.46)$$
$$I_{rg\,ratio\,high} = I_{rg\,tributary} \bullet (1.2)$$

where:

$I_{rg\,ratio\,low}$ is the Rio Grande low ratio inflow, in acre-feet

$I_{rg\,ratio\,high}$ is the Rio Grande high ratio inflow, in acre-feet

Operationally, a determination of the Rio Grande inflow is needed before the end of the month, the choice of which ratio inflow to use is based on the value determined by the following equation, rather than 360 acre-feet.

$$Q_{test} = (360/30) \bullet CD$$

where:

Q_{test} is value to test for ratio, in acre-feet

CD is the day of the month the calculations are made.

After the decision is made as to which ratio inflow is to be used, the daily values are summed and if the resultant is negative, the value of the ratio inflow is set to zero (this rule is only applied monthly or to the daily cumulative value in the daily program). This method also has inherent problems, in that is relies on streamflow measurements at the Azotea outlet and the above Heron gages to produce accurate results. One or both gages may be off to the relative magnitude of the real difference of the flows, producing questionable results (i.e., negative Rio Grande inflows).

Seepage Method

After the initial filling of Heron Reservoir, seepage from the reservoir was observed. This observed seepage was confined to a channel and was of sufficient quantities that it could be measured. It was agreed upon by leading agencies that this seepage be accounted as native water, because to account it as San Juan-Chama water would result in releases of water during times when no demands for the water existed, and no account to charge it to. Algorithms were developed to predict seepage based on water surface elevation. The seepage method is considered as part of the natural release from the reservoir (this method was adopted in 1988). Since there is no Rio Grande storage allowed in Heron Reservoir, the Rio Grande inflow that enters the reservoir should at least be equal to the amount of Rio Grande outflow that is due to seepage.

The seepage from the reservoir is calculated by the equation:

$$Seep = (Elev_r - 7100) \bullet 0.02134 + 0.76$$

where:

$Seep$ is seepage from the reservoir, in cfs

$Elev_r$ is reservoir elevation, in feet.

Note: When the reservoir water surface elevation is below 7,064 feet the computation produces negative results, in which case, the seepage value is set to zero.

Net End-of-Month Gain Method

The net end-of-month gain method attempts to compute the unmeasured Rio Grande inflow during the month and is a variation on the Heron Reservoir mass balance equation. The calculations for this method are made on a daily basis. The results are summed for an end of month determination or if the month is not over, a “cumulative to date” determination is performed.

Rearranging the general mass balance equation and substituting the inflow from the ratio inflow gives:

$$S_t - S_{t-1} + O_{rg} + O_{sjc} - I_{sjc} - I_{rg\,ratio} - P_t + E_t = 0$$

The total precipitation (P_t) that falls on the reservoir is divided up as shown in the following equation. One part of the precipitation is labeled Rio Grande and consists of the amount of precipitation that would have returned to the river system and would not have been lost to evapotranspiration or soil moisture before the reservoir was built. The other portion of the precipitation is labeled San Juan-Chama and is the amount of precipitation that would have been lost to the river system if the reservoir were not there. This pre-reservoir loss of precipitation is known as effective precipitation. Effective Precipitation is the portion of the precipitation that would be consumed by evapotranspiration or infiltrate into the soil. The effective precipitation is computed based on accumulated actual precipitation for the month. See **Table 2** for a tabulation of effective precipitation for Heron Reservoir.

$$P_t = P_{eff} + P_{rg}$$

where:

P_{eff} is effective precipitation (San Juan-Chama precipitation), in acre-feet per day

P_{rg} is Rio Grande precipitation, in acre-feet per day.

Substituting the parts of precipitation gives:

$$S_t - S_{t-1} + O_{rg} + O_{sjc} - I_{sjc} - I_{rg\,ratio} - P_{eff} - P_{rg} + E_t = 0$$

If one considers the Rio Grande portion of the precipitation as part of the total reservoir end of day gain then the previous equation can be rearranged to:

$$S_t - S_{t-1} + O_{rg} + O_{sjc} - I_{sjc} - I_{rg\,ratio} - P_{eff} + E_t = G_{ed}$$

where:

G_{ed} is end of day gain, in acre-feet.

The net end of day gain is the Rio Grande gain on the reservoir. To remove the San Juan-Chama component of gain, the precipitation that is considered San Juan-Chama (the effective precipitation) is removed from the equation. Since only San Juan-Chama water is allowed to be stored in the reservoir, the only evaporation that can occur is San Juan-Chama water. Therefore, the evaporation is also removed from the Rio Grande gain equation leaving the following equation for net end of day gain.

$$S_t - S_{t-1} + O_{rg} + O_{sjc} - I_{sjc} - I_{rg\,ratio} = NG_{ed}$$

where:

NG_{ed} is net end of day gain, in acre-feet.

As can be seen in this equation, the Rio Grande gain (net end of day gain) is any Rio Grande component of precipitation plus any unaccounted for gains on the reservoir. This method can also result in negative end of month storages indicating that this method can be invalid.

Table 2. Effective Precipitation Table

PRECIP. AMOUNTS THRU END OF MONTH	HERON	EL VADO	ABIQUIU	COCHITI	JEMEZ	ELEPHANT BUTTE
0” to 1”	95%	100%	100%	95%	95%	100%
>1” to 2 “	90%	100%	100%	90%	90%	100%
>2” to 3”	82%	100%	100%	82%	82%	100%
>3” to 4”	65%	50%	50%	65%	65%	100%
>4” to 5”	45%	50%	50%	45%	45%	100%
>5” to 6”	25%	50%	50%	25%	25%	100%
>6”	5%	50%	50%	5%	5%	100%

Determination of Rio Grande Inflow

Once the various methods for determining the Rio Grande inflow have been computed a decision is made, through a series of logical expressions, on which method or combination of methods that provides the most accurate estimate of Rio Grande inflow. When the Heron Reservoir inflow is calculated before the end of the month, the cumulative totals to the calculation date are used with the logical expressions.

The logical expressions used to determine Rio Grande inflow are given below: (Note that a new variable is introduced in the water accounting report (Table 1 - Apparent Inflow To Heron Reservoir – column 6), "tributary inflow within" Heron Reservoir. This variable presents the result of the logical tests, and is assigned the value of seepage, net end of month/day gain, or 0)

If $NG_{ed} < 0$

then $NG_{ed} = 0$

If $NG_{ed} > Seep$

then $I_{within} = NG_{ed}$

else $I_{within} = Seep$

If $NG_{ed} = 0$ and $I_{rg\ ratio} > Seep$

then $I_{within} = 0$

If $I_{rg\ ratio} > Seep$

then $I_{RG} = I_{rg\ ratio} + I_{within}$

else $I_{RG} = I_{rg\ ratio}$

where:

I_{within} is tributary inflow within Heron reservoir, in acre-feet

The combination methods are referred to as hybrid methods that are actually variations of the mass balance inflow. Since the ratio method is part of each of the hybrid methods, they will be referenced by the other component of the method, i.e., the seepage hybrid method (seepage plus ratio) or the net end of month/day gain hybrid method (net end of month/day gain plus ratio).

The logical expressions can also be represented without introducing the "tributary inflow within" variable and arranged as follows: (This seems to make it somewhat more intuitive on which method is selected to estimate the Rio Grande inflow to Heron Reservoir):

If $Seep > NG_{ed}$,then

If $Seep \geq I_{rg\ ratio}$, then

$I_{RG} = Seep$

else

If $NG_{ed} \leq 0$, then

$I_{RG} = I_{rg\ ratio}$

else

$I_{RG} = Seep + I_{rg\ ratio}$

else

If $Seep \geq I_{rg\ ratio}$, then

$$I_{RG} = NG_{ed}$$

else

$$I_{RG} = NG_{ed} + I_{rg\ ratio}$$

Summarizing the above logical expressions:

1. Use the largest result from the three primary methods (ratio seepage, net end of month/day gain) when at least one of the other methods is less than seepage and/or the net end of month/day gain method produces a negative result.

2. Use the result from the seepage method when it is greater than both the ratio and net end of month/day gain methods (i.e., the Rio Grande inflow is never less than the Rio Grande release determined by the seepage method).

3. Use the result from the ratio method when it is greater than the seepage method and the net end of month/day gain method results in negative values. This does not produce the same result as only testing that the ratio method is greater than both the seepage and net end of month/day gain methods. The net end of month/day gain method must be less than or equal to zero for the ratio method to be invoked.

4. Use the result from the end of month/day method when it is greater than the seepage method and the seepage method is greater than the ratio method. This does not produce the same result as only testing that the end of month/day method is greater than both the seepage and ratio methods. The seepage method must be greater than the ratio method for the net end of month/day gain method to be invoked.

5. Use one of the hybrid methods when both the ratio and end of month/day methods provide positive results, and at least one of the methods is greater than seepage.

6. Use the result from the seepage hybrid method when the seepage method is greater than the net end of month/day method, and statement 5 is true.

7. Use the result from the end of month/day method when it is greater than the seepage method, and statement 5 is true. Note that this is the same as the general Heron Reservoir mass balance equation, computing the Rio Grande inflow less the net evaporation term.

Storage and Loss Calculations

All losses on Heron Reservoir are losses from the San Juan-Chama Pool. There are no losses from the temporary Rio Grande pool. The equations for San Juan-Chama loss from the reservoir are:

$$S_{rg_t} = S_{rg_{t-1}} - O_{rg} + I_{rg}$$
$$S_{sjc_t} = S_T - S_{rg_t}$$
$$NL_{sjc} = \left(S_{sjc_{t-1}} - S_{sjc_t}\right) + I_{sjc} - O_{sjc}$$
$$NL_{phy} = E_t - P_t$$

An adjustment variable reconciles the difference between the total water loss calculations and the San Juan-Chama loss calculations.

$$NL_{adj_t} = NL_{phy_t} - NL_{sjc_t}$$

This adjustment factor reconciles any unidentified loss due to evaporation, or inaccuracies in gage measurements.

El Vado Reservoir

El Vado Dam was originally constructed to provide conservation storage for a supplemental irrigation supply for the MRGCD lands along the Rio Grande from Cochiti Dam to below Socorro, New Mexico. Because El Vado Dam was constructed after 1929 (completed in 1935), the operation of the reservoir for storage and release of Rio Grande water is subject to the Rio Grande Compact. Water imported into the Rio Grande basin via the San Juan-Chama Project and stored in El Vado Reservoir is not subject to storage and release restrictions of the Rio Grande Compact.

Operation for Rio Grande Water

The basic concept in operating El Vado Reservoir involves the storage of natural inflow that is in excess of current MRGCD and other needs below El Vado Dam. The major storage season is during the spring runoff, and then storage can be released during the irrigation season to users in the Middle Rio Grande Valley as needed.

Restrictions of the Rio Grande Compact

Article VII of the Rio Grande Compact provides that no storage of Rio Grande water in El Vado Reservoir can take place when usable water in Project Storage (storage in Elephant Butte and Caballo Reservoirs) is less than 400,000 acre-feet. Article VI provides that any Rio Grande water stored in El Vado Reservoir must be held in storage to the extent of New Mexico's accrued debit under the Compact. Nearly all of the post-compact storage capacity in New Mexico is located in El Vado Reservoir.

Water Right Constraints on Operation of Rio Grande Water

El Vado is operated to store native water for the Six Middle Rio Grande Pueblos of; Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia and Isleta. The Bureau of Indian Affairs and the Bureau of Reclamation compute the amount of storage required and release of Indian storage is made only when the natural flow of the Rio Grande is insufficient to adequately supply irrigation to 8,847 acres of Indian lands.

Additionally, no storage of native water can be made at El Vado Reservoir when to do so would deprive acequias along the Rio Chama downstream of El Vado of water to which they are entitled. In 1971 the State Engineer required that El Vado Reservoir be operated during the irrigation season to pass all the natural flow of the Rio Chama up to 100 cfs, as measured below Abiquiu Dam, during the irrigation season.

Operation for San Juan-Chama Water

El Vado Reservoir operation is affected by the San Juan-Chama Project in two ways. The first is that San Juan-Chama Project water released from Heron Dam for use downstream of El Vado Reservoir is simply passed through. The second is that storage of large volumes of San Juan-Chama Project water in El Vado Reservoir may take place for extended periods of time. The MRGCD has contracted for 20,900 acre-feet per year of San Juan-Chama Project water and maintains as much of this water in El Vado Reservoir as conditions permit. In addition, the MRGCD has contracted with various contractors of San Juan-Chama Project water to allow for their storage in El Vado Reservoir.

Rio Grande and San Juan-Chama Storage Calculations

Total water storage is determined using elevation-capacity tables. This total storage is divided into Rio Grande and San Juan-Chama Project storage. The latter is further divided into individual contractor accounts. The general equation for calculation of the San Juan-Chama storage is

$$S_{sjc_t} = S_{sjc_{t-1}} + I_{sjc_t} - O_{sjc_t} - NL_{sjc_t}$$

where:

S_{sjc_t}	is	San Juan-Chama storage, in acre-feet
$S_{sjc_{t-1}}$	is	San Juan-Chama storage, in acre-feet
I_{sjc_t}	is	San Juan-Chama inflow, in acre-feet
O_{sjc_t}	is	San Juan-Chama outflow, in acre-feet

The equation for calculating Rio Grande Storage is

$$S_{rg_t} = S_{T_t} - S_{sjc_t}$$

where:

S_{rg_t}	is	Rio Grande storage, in acre-feet
S_{T_t}	is	total physical storage, in acre-feet

Loss Calculations

In general, the losses are computed for three different conditions: (1) natural losses with no reservoir (pre-reservoir), (2) losses with only Rio Grande water stored (a pre-San Juan-Chama Project condition, i.e. hypothetical), and (3) losses under actual conditions with both Rio Grande and San Juan-Chama waters in storage (present condition). A “control area” is defined so that each of the three conditions can be compared to each other. While the total area is the same from condition to condition, the composition of the control area changes with and without the lake area condition described below. If the reservoir is completely iced-over, all of the losses are set to zero.

The generalized computations for the physical accounting loss computations are described in the following sections. This procedure is repeated in similar form for the remainder of the reservoirs in the model.

Control Area

The control area is an area around and including the lake generally corresponding to the reservoir area at a high pool level, such as top of flood control or conservation pool (**Figure 1**). The control area is divided into five different areas: barren, irrigated, meadow, river, and lake areas. Losses are computed for each type of area as follows:

$$L_{ba} = A_{b\cdot} \bullet P_{eff} \bullet AP_{ows}$$

$$L_{ia} = A_i \bullet LR_{ia} \bullet AP_{ows}$$

$$L_{ma} = A_m \bullet LR_{ma} \bullet AP_{ows}$$

$$L_{ra} = A_r \bullet E_t \bullet AP_{ows}$$

$$L_{la} = A_l \bullet E_t \bullet AP_{ows}$$

where:

L_{ba}	is	barren area loss, in acre-feet
A_b	is	barren area, in acres
P_{eff}	is	effective precipitation, in acre-feet
L_{ia}	is	irrigated area loss, in acre-feet
A_i	is	irrigated area, in acres
LR_{ia}	is	irrigated area loss rate, in feet
AP_{ows}	is	open water surface area, in percentage
L_{ma}	is	meadow area loss, in acre-feet
A_m	is	meadow area, in acres
LR_{ma}	is	meadow area loss rate, in feet
L_{ra}	is	river area loss, in acre-feet
A_r	is	river area, in acres
E_t	is	lake evaporation, in feet
L_{la}	is	lake area loss, in acre-feet
A_l	is	lake area, in acres

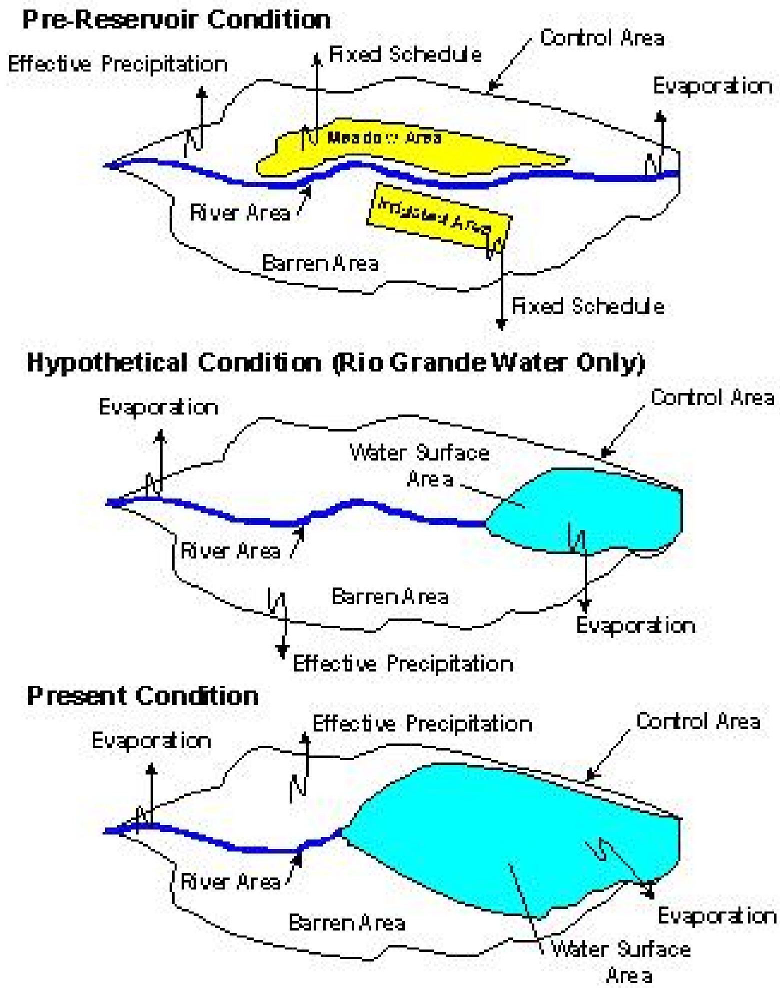

Figure 1. Diagram Showing Control Area of Reservoirs.

See **Table 3** for a tabulation of barren, irrigated and meadow area values used at El Vado Reservoir.

See **Table 2** for a tabulation of effective precipitation used at El Vado Reservoir.

Irrigated and Meadow Loss Rates are pre-defined rates for each type and month.

Lake Evaporation is Pan Evaporation (when measured) times a pan evaporation coefficient of 0.70 or is average temperature times a monthly K Factor when the pan is frozen and not in use.

Open Water Surface Area Percentage is the percentage of the lake area which is open or not covered by ice.

Pre-reservoir Condition

The pre-reservoir condition approximates natural losses in the control area without the reservoir. The area of each of the five types of areas is fixed (see Figure 1). The loss from the pre-reservoir condition is calculated by the equation:

$$L_{pr} = L_{ba} + L_{ia} + L_{ma} + L_{ra}$$

where:

L_{pr} is pre-reservoir condition loss, in acre-feet

Present Condition

The present condition approximates the current losses in the control area under present reservoir conditions (see Figure 1). The lake area is computed from the reservoir area-capacity table based on today's observed lake elevation. The river area is also based on the observed lake elevation and a table of lake elevation versus river area. The barren area is the control area less the lake and river areas. The irrigated and meadow areas are assumed to be inundated by the reservoir. The loss from the present condition is calculated by the equation:

$$L_p = L_{ba} + L_{ra} + L_{la}$$

where:

L_p is present condition loss, in acre-feet

L_{ra} is river area loss, in acre-feet (based on observed elevation)

L_{la} is lake area loss, in acre-feet (based on observed elevation)

Hypothetical Condition

The hypothetical condition approximates the losses in the control area without San Juan-Chama Project water. The lake area is computed from the reservoir area-capacity table based on the hypothetical lake elevation if only Rio Grande water was stored. The river area is also based on the "Rio Grande only" lake elevation and the relationship of river area versus lake elevation. The barren area is the control area less the lake and river areas. The irrigated and meadow areas are assumed to be inundated by the reservoir. The loss from the hypothetical condition is calculated by the equation:

$$L_h = L_{ba} + L_{ra} + L_{la}$$

where:

L_h is hypothetical condition loss, in acre-feet

L_{ra} is river area loss, in acre-feet (based on Rio Grande pool "elevation")

L_{la} is lake area losses, in acre-feet (based on Rio Grande pool "elevation")

Computation of the Rio Grande water content for the hypothetical condition on a given day is not straightforward because the losses are dependent on the content and the content is dependent on the losses. A reiteration algorithm was developed in the daily programs to determine the Rio Grande content, water surface area and losses, for use in all the programs. The algorithm first estimates the Rio Grande content for a given day using the previous day's Rio Grande content. The Rio Grande losses are computed based on this estimated content. The Rio Grande content is then recomputed and compared to the prior value. If they are within 0.5 acre-feet, the latest Rio Grande content is accepted. If not an iteration process is initiated using the last computed Rio Grande content and re-computing Rio Grande losses until the criterion is met. The SJC content is computed by subtracting the Rio Grande content and, if applicable, sediment accumulation from the total content.

Net Losses

Net losses, which are applied to the San Juan-Chama and Rio Grande pool, are the losses in excess of the natural, pre-reservoir condition losses. These net losses are computed from the three conditions listed above as follows:

$$NL_{sj} + NL_{rg} = L_p + L_{pr}$$

and

$$NL_{sj} = L_p - L_h$$

and

$$NL_{rg} = L_h - L_{pr}$$

where:

NL_{sjc} is net San Juan-Chama loss, in acre-feet

NL_{rg} is net Rio Grande loss, in acre-feet

Reconciling Losses

The difference in the accounting losses based on water type and ownership will be different than the losses based on the total water physical system. The differences should be handled by the equation:

$$NL_{adj_r} = NL_{sj_t} + NL_{rg_t} - NL_{phy_t}$$

where:

NL_{adj_t} is daily net loss adjustment, in acre-feet.

The adjustment will be made on the accounting and not on the physical side of the model.

Abiquiu Reservoir

Operation for Rio Grande Water

Abiquiu Dam and Reservoir is operated for flood and sediment control in accordance with conditions and limitations stipulated in the Flood Control Act of 1960 (PL 86-645). Reservoir regulation for flood control is also coordinated with the operation of Jemez Canyon Reservoir, Cochiti Lake, and Galisteo Reservoir. Abiquiu Reservoir is operated to limit flow in the Rio Chama, insofar as possible, to the downstream channel capacities of 1,500-1,800 cfs for the reach below Abiquiu Dam, 3,000 cfs for the reach below the Rio Chama at Chamita stream gage, and on the Rio Grande main stem, 10,000 cfs for the reach below the Rio Grande at Otowi stream gage. Irrigation releases from El Vado Reservoir are passed through the reservoir. Typically, if Rio Grande inflows exceed downstream channel capacities during April and May, Abiquiu captures this peak of snowmelt runoff, and releases it during June and early July. However, any Rio Grande storage remaining after the natural flow at Otowi drops below 1,500 cfs (July 1st or later) is carried over and not released until November 1st or later.

Unlike Heron and El Vado Reservoirs, the sediment deposition at Abiquiu Reservoir is of sufficient magnitude to impact storage and water accounting computations. The reservoir area is resurveyed every five to seven years. Between surveys, the sediment deposition is estimated based on inflow and reservoir storage, and SJ-C contractor storage spaces are reduced as sediment partially displaces them. A detailed description of sediment deposition computations may be found later in this document.

Operation for San Juan-Chama Water

In 1981, PL 97-140 authorized the storage of 200,000 acre-feet of San Juan-Chama water in Abiquiu Reservoir. The City of Albuquerque has obtained a storage easement to elevation 6,220 feet. Real estate interests have not been obtained above elevation 6,220 feet to accommodate the full 200,000 acre-feet as authorized. The San Juan–Chama capacity is annually reduced due to the estimated sediment deposition. San Juan-Chama storage is held below elevation 6,220 feet and released as requested by the storing entities. The San Juan-Chama pool also serves to increase the sediment trap efficiency, and enhance the recreation, fish and wildlife opportunities in the reservoir.

Rio Grande and San Juan-Chama Storage Calculations

The last sediment survey for Abiquiu Reservoir was made in June, 1997. The area-capacity table currently being used was made effective January 1, 1999. This area-capacity table indicated that the San Juan-Chama contractors had 183,881 acre-feet available for water storage at that time, based on the City of Albuquerque land easement at elevation 6220.00 NGVD.

Sediment Deposition Computations

The goal of sediment computations is to estimate the storage capacity lost to sediment deposition between surveys, during which time the sediment deposition is estimated based on inflow and reservoir storage. The sediment computation is a multi-step process that results in an estimated volume lost to sediment in both the flood and conservation pools. Only the estimated sediment deposition in the conservation pool is accumulated month by month, until the adoption of a new area-capacity table as a result of a sediment survey.

The term "conservation" indicates non-flood water. The phrases "top of conservation" or "conservation capacity" are used to designate the reservoir capacity for storing non-flood water. This conservation capacity level is used as a fixed elevation to compute the amount of sediment deposition distributed to the conservation space and to the flood control space.

The total suspended sediment load for the reservoir is computed using a daily inflow value and coefficient based on the time of year. For Abiquiu Reservoir, sediment concentrations vary depending on the time of year. An exponential equation is used to compute the suspended sediment load. The equation is valid for a given range of inflows and takes the following general form:

$$Sed_s = coeff \bullet I^{\exp}$$

where:

Sed_s is suspended sediment load in acre-feet

coeff is coefficient based on inflow

I is total inflow in acre-feet

exp is exponent based on flow

The volume of sediment deposited above the permanent pool is determined as follows:

$$P_{fp} = \frac{E_{ws} - E_{tc}}{E_{tc} - E_z} \bullet coif^{(exp)}$$

where:

E_{ws} is present water surface elevation, in feet
E_{tc} is top of conservation pool elevation, in feet (el. 6220.0)
E_z is zero storage elevation, in feet (6075.0 ft.)
P_{fp} is percent of sediment in the flood pool
coeff is flood pool coefficient

Because the level of Abiquiu Reservoir does not remain constant due to various storage and release requirements of San Juan-Chama water, it was concluded that the same sediment unit weight would be used for both the flood pool and conservation pool. The volumes of sediment deposited in the conservation pool is determined by the equation:

$$Sed_{vpp} = \left(Sed_s \bullet TE \bullet 2000 \bullet 1\text{-}\, \mathrm{P_{fp}}\right) / D_{pp} \bullet \; 43560$$

where:
Sed_{vpp} is sediment deposited in the conservation pool, in acre-feet
TE is trap efficiency (87% for Abiquiu Reservoir)
D_{pp} is sediment density in permanent (conservation) pool

Sediment Content Effects

Abiquiu Reservoir storage computations are affected by sediment accumulation carried in from inflows. Once the sediment quantity has been calculated for the conservation pool (below elevation 6220), this amount, Sed_{vpp}, is applied toward the current Rio Grande content. The San Juan-Chama and Rio Grande content are calculated based on the following equations:

$$S_{sjc_t} = S_{sjc_{t-1}} + I_{sjc_t} - O_{sjc_t} - NL_{sjc_t}$$
$$S_{rg_t} = S_{T_t} - S_{sjc_t} - Sed_{vpp}$$

Sediment displaces some of the total capacity of the reservoir on a daily basis. For accounting purposes, it is important to calculate accurate capacities of the San Juan-Chama pools without sediment estimates during the year with one sediment adjustment made at the end of the year. The sediment calculation computed by the daily program is only an estimate until an official sediment survey is performed on the reservoir, and the current reservoir capacity is accurately known.

The total sediment accumulation for the calendar year, estimated by the sediment computation process, that is accounted for in the Rio Grande content is adjusted and is applied toward San Juan-Chama Project contractor pools at the end of each year at Abiquiu Reservoir. The City of Albuquerque has the largest allocation in the conservation pool. Reductions in San Juan-Chama contractor storage space are applied to other contractors first. Once sediment has replaced these other pools, the sediment will begin reducing the City of Albuquerque pool. This arrangement is based on contractor agreements with the City of Albuquerque.

The sediment estimate is also used as a daily tool for water managers in determining any Rio Grande or “incidental” water that is in the reservoir. For details on Rio Grande carryover, lock in criteria, incidental storage and losses, refer to Abiquiu Loss Calculations. A “Hold Pool” is calculated on a daily basis and is calculated as follows:

$$S_{hp} = S_{sjc_t} + Sed_{vpp} + S_{rg}$$

where:

S_{hp} is Hold Pool content, in acre-feet

S_{rg} is Rio Grande content, in acre-feet.

This Hold Pool computation is the authorized storage in Corps of Engineers reservoirs used to determine the amount of incidental Rio Grande or “natural” to be evacuated or carried over.

Loss Calculations

Net losses to the San Juan-Chama and the Rio Grande (natural) storage are calculated for Abiquiu Reservoir using the same method as El Vado Reservoir, except when natural water stored during spring runoff is “locked-in”. See **Table 1** for a tabulation of effective precipitation used at Abiquiu Reservoir. See **Table 3** for a tabulation of barren, irrigated and meadow area values used at Abiquiu Reservoir.

Carryover Storage

Carryover storage in Abiquiu Reservoir occurs when, after July 1 of each year with the natural inflow (i.e., exclusive of water derived from release from storage upstream) to Cochiti Lake is less than 1,500 cfs, while at the same time there is at least 212,00 acre-feet of flood control capacity available at Cochiti Reservoir. This storage is the result of high inflows coming into the reservoir during spring runoff. As previously stated, the Corps has downstream release restrictions that prohibit passing all of the natural inflow. The Rio Chama has a channel capacity of 1,800 cfs below Abiquiu Reservoir, flows must not exceed 3,000 cfs at Chamita gage and there must be no more than 10,000 cfs at the Otowi gage. These restrictions result in temporary storage of natural water as well as releasing as much as downstream restrictions allow. Depending on the volume of water from spring runoff, Abiquiu Reservoir has either been able to safely pass inflow without any carryover or has locked-in as little as 3,500 (1994) acre-feet to as much as 212,000 acre-feet (1987).

The natural that is locked-in must remain in storage until the end of irrigation season (November 1). Any natural inflow to the reservoir during the lock-in period is passed through the reservoir. After November 1, the Corps can release the carryover, and releases are planned to benefit minimum flows during the winter.

Carryover Loss

Losses during the lock-in period are modified slightly to account for losses on natural storage. Natural losses between carryover and incidental pools are prorated resulting in the losses being distributed by percent storage. Carryover loss is calculated using the following equation:

$$Loss_c = Loss_t \bullet \frac{S_c}{S_t}$$

where:

$Loss_c$ is carryover loss, in acre-feet per day

$Loss_t$ is total loss, in acre-feet per day

S_c is carryover storage, in acre-feet per day

S_t S_t is total storage, in acre-feet per day

Cochiti Reservoir

Operation for Rio Grande Water

Cochiti Dam was authorized by Congress in 1960 for flood and sediment control. Operating rules specified in P. L. 86-485 provide that the Dam is to be operated to bypass the maximum possible rate of flow that can be carried in the channel through the middle valley without causing flooding. When inflow exceeds the capacity of the downstream channel, storage is retained in the reservoir and held until downstream channel conditions allow, provided that, after July 1, there is 1500 cfs or more of native inflow and that a minimum of 212,000 acre-feet of storage is available in Cochiti Reservoir to control summer flood flows. Flood storage that is "locked-in" is released beginning November first. (see discussion under carry-over storage at Abiquiu Reservoir)

Operation for San Juan-Chama Project Water

Public Law 88-293 authorized the release of 50,000 acre-feet of San Juan-Chama Project water for the initial filling of a permanent pool of 1200 acres in Cochiti Reservoir, and thereafter sufficient water annually to offset the evaporation from such area. A portion of the release of San Juan-Chama Project water is used to offset evaporation loss from the water surface of a small wetland on the Santa Fe River above Cochiti Dam.

Rio Grande and San Juan-Chama Storage Calculations

The last sediment survey for Cochiti Lake was in June, 1998, and the current area-capacity table was made effective January 1, 1999. This area-capacity table shows that the San Juan-Chama Project recreation pool of 1,200 acres occupies a volume of 49,359 acre-feet at elevation 5340.10.

Sediment Deposition Computations

The total suspended sediment load for the reservoir is computed using a daily inflow value and coefficient based on the time of year and flow. Sediment concentrations vary depending on the time of year and inflow. Thunderstorms are usually associated with high sediment concentrations while spring runoff from the high mountains tends to have lower sediment concentrations. Because of the varying flow and sediment concentration conditions, the year is divided into four periods to compute sediment deposition: October through February; March through May; June, and July through September. For each of these periods, one to three exponential equations are used to compute the suspended sediment load. Each equation is valid for a given range of inflows. Bedload component of total load is based on a single flow dependent relationship used throughout the year. The suspended sediment equations take the following general form:

$$Sed_s = coeff \bullet I^{\exp}$$

where:

Sed_s is sediment load in acre-feet

coeff is coefficient based on season and inflow

I is total inflow in acre-feet

exp is an exponent

The volume of sediment deposited above the permanent pool is determined as follows:

$$P_{fp} = \frac{E_{ws} - E_{tc}}{E_{tc} - E_z} \bullet \text{coeff}^{(\text{exp})}$$

where:
E_{ws} is present water surface elevation, in feet
E_{tc} is top of recreation pool elevation, in feet (el. 5340.10)
E_z is zero storage elevation, in feet (5247.0 ft.)
P_{fp} is percent of sediment in the flood pool
coeff is flood pool coefficient

The same sediment unit weight is used for both the flood pool and recreation pool. The volume of sediment deposited in the recreation pool is determined by the equation:

$$Sed_{vpp} = \left(Sed_t \bullet TE \bullet 2000 \bullet 1\text{-}\,\mathrm{P_{fp}}\right) / D_{pp} \bullet 43560$$

where:
Sed_{vpp} is sediment deposited in the conservation pool, in acre-feet
TE is trap efficiency (87% for Cochiti Lake)
D_{pp} is sediment density in permanent (conservation) pool
Sed_t is total load; suspended sediment (Sed_s) and bed load

Sediment Content Effects

Once the sediment quantity has been calculated for the recreation pool (below elevation 5340.10), this amount, Sedvpp, is applied toward the current Rio Grande content. The San Juan-Chama and Rio Grande content are calculated based on the following equations:

$$S_{sjc_t} = S_{sjc_{t-1}} + I_{sjc_t} - O_{sjc_t} - NL_{sjc_t}$$

$$S_{rg_t} = S_{T_t} - S_{sjc_t} - Sed_{ypp}$$

The sediment calculation computed by the daily program is only an estimate until an official sediment survey is performed on the reservoir, and the current reservoir capacity is accurately known. The total sediment accumulation for the calendar year, estimated by the sediment computation process, that is accounted for in the Rio Grande content is adjusted and is applied toward San Juan-Chama Project recreation pool at the end of each year.

The sediment estimate is also used as a daily tool for water managers in determining any Rio Grande or "incidental" water that is in the reservoir. For details on Rio Grande carryover, lock in criteria, incidental storage and losses, refer to the section entitled Abiquiu Reservoir Loss Calculations. A "Hold Pool" is calculated on a daily basis and is calculated as follows:

$$S_{hp} = S_{sjc_t} + Sed_{vpp} + S_{rg}$$

where:
S_{hp} is Hold Pool content, in acre-feet
S_{rg} is Rio Grande content, in acre-feet.

Loss Calculations

Net losses to the Rio Grande (natural) and San Juan-Chama Project water in the recreation pool are calculated for Cochiti Lake using the same method described in the El Vado loss calculations. The total control area at Cochiti Lake is 7780 acres. See **Table 2** for a tabulation of effective precipitation used at Cochiti Lake. See **Table 3** for a tabulation of barren, irrigated and meadow area values used at Cochiti Lake.

Jemez Canyon Reservoir

Jemez Canyon Dam and Reservoir was authorized by the Flood Control Act of 1948, and is operated in tandem with Cochiti Lake to control flows through the middle valley. Since 1979, a sediment control pool has been established and maintained within that portion of the reservoir capacity allocated for sediment deposition. The water stored in the pool is scheduled to be completely evacuated by 2002. Flood storage, if any, is accumulated atop the sediment control pool and released as soon as possible thereafter. Jemez Canyon Reservoir is operated to prevent carryover storage of floodwater.

Rio Grande and San Juan-Chama Storage Calculations

The last sediment survey of Jemez Canyon Reservoir was in June, 1998. The area-capacity table currently used was effective January 1, 1999. Approximately 24,425 acre-feet of storage capacity remains in the allocated sediment control pool.

Sediment Deposition Computations.

The total suspended sediment load for the reservoir is computed using a daily inflow value and coefficient valid for a given range of inflow over the entire year. Bedload component is not used. This equation takes the following general form:

$$Sed_s = coeff \bullet I^{\exp}$$

where:

Sed_s is suspended sediment load in acre-feet

coeff is coefficient based on inflow

I is total inflow in acre-feet

exp is exponent

The volume of sediment deposited above the sediment control pool is determined as follows:

$$P_{fp} = \frac{E_{ws} - E_{tc}}{E_{tc} - E_z} \bullet \text{coeff}^{(\text{exp})}$$

where:
E_{ws} is present water surface elevation, in feet
E_{tc} is top of sediment control pool elevation, in feet (el. 5198.13)
E_z is zero storage elevation, in feet (5155.10 ft.)
P_{fp} is percent of sediment in the flood pool

coeff is flood pool coefficient

The volume of sediment deposited in the sediment control pool is determined by the equation:

Sed_{vpp} = (TE

where:

Sed_{vpp} is sediment deposited in the *recreation* pool, in acre-feet
TE is trap efficiency (96.5% for Jemez Canyon Reservoir)
D_{pp} is density of sediment deposited in sediment control pool
Sed_t is total sediment load (suspended plus bed load, if any)

Sediment Content Effects

Once the sediment quantity has been calculated for the sediment control pool (below elevation 5198.13), this amount, Sed_{vpp}, is applied toward the current Rio Grande content. The San Juan-Chama and Rio Grande content are calculated based on the following equations:

$$S_{sjc_t} = S_{sjc_{t-1}} + I_{sjc_t} - O_{sjc_t} - NL_{sjc_t}$$

$$S_{rg_t} = S_{T_t} - S_{sjc_t} - Sed_{ypp}$$

Loss Calculations

Net losses to the Rio Grande (natural) and San Juan-Chama Project water in the sediment control pool are calculated for Jemez Canyon Reservoir using the same method described in the El Vado loss calculations, with some exceptions. The effective precipitation **(Table 2)** is used to compute net Rio Grande plus San Juan-Chama Project losses. Effective precipitation on the barren area functions as the pre-reservoir condition loss. See **Table 3** for a tabulation of barren, irrigated and meadow area values used at Jemez Canyon Reservoir.

Elephant Butte Reservoir

Operation for Rio Grande Water

Elephant Butte Reservoir is the principal storage facility for the Rio Grande Project, delivering stored water for downstream use under contract between the Bureau of Reclamation and the Elephant Butte Irrigation District in New Mexico and the El Paso County Water Improvement District in Texas. Elephant Butte Reservoir is also operated to ensure that the U. S. 1906 Treaty obligation with Mexico to deliver 60,000 acre-feet per annum at the Acequia Madre headgate in Mexico can be met.

Operation for San Juan-Chama Project Water

In 1981, Congress authorized the Secretary of the Interior to enter into contracts for storage of San Juan–Chama Project water in Elephant Butte Reservoir. This Act (P. L. 97-140) provided that the amount of evaporation loss and spill chargeable to San Juan-Chama Project water shall be accounted under procedures established by the Grande Compact Commission.

San Juan-Chama Project Water may also stored in Elephant Butte Reservoir for recreation purposes. Originally established at 50,000 acre-feet, water in the recreation pool has been substantially diminished in size because of spill of this water from Elephant Butte Reservoir.

Loss Calculations

In accounting of reservoir losses at Elephant Butter Reservoir, the effective precipitation used **(Table 2)** to compute pre-reservoir condition losses See **Table 3** for a tabulation of barren, irrigated and meadow area values used at Elephant Butte Reservoir.

Table 3. Reservoir Areas Used in Loss Computations.

RESERVOIR	Barren	Irrigated	Meadow and Town	River Channel	Lake
EL VADO					
Pre-Reservoir	1420 ac.	300 ac.	1460 ac.	200 ac.	N/A
Hypothetical	0 to 3180 ac.	(inundated)	(inundated)	0 to 200 ac.	0 to 3380 ac.
Present	0 to 3180 ac.	(inundated)	(inundated)	0 to 200 ac.	0 to 3380 ac.
ABIQUIU					
Pre-Reservoir	7189 ac.	N/A	N/A	288 ac.	N/A
Hypothetical	0 to 7189 ac	N/A	N/A	0 to 288 ac.	0 to 7477 ac.
Present	0 to 7189 ac	N/A	N/A	0 to 288 ac.	0 to 7477 ac.
COCHITI					
Pre-Reservoir	6900 ac.	40	N/A	840 ac.	N/A
Hypothetical	0 to 6900 ac.	(inundated)	N/A	0 to 840 ac.	0 to 7780 ac.
Present	0 to 6900 ac.	(inundated)	N/A	0 to 840 ac.	0 to 7780 ac.
JEMEZ CANYON					
Pre-Reservoir	N/A	N/A	N/A	N/A	N/A
Hypothetical	N/A	N/A	N/A	N/A	Water surface area (varies)
Present	N/A	N/A	N/A	N/A	Water surface area (varies)
ELEPHANT BUTTE					
Pre-Reservoir	N/A	N/A	N/A	N/A	N/A
Hypothetical	N/A	N/A	N/A	N/A	Water surface area (varies)
0	N/A	N/A	N/A	N/A	Water surface area (varies)